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# LANL / J-4 Technology for IAEA Seals

## Spectral Interferometry

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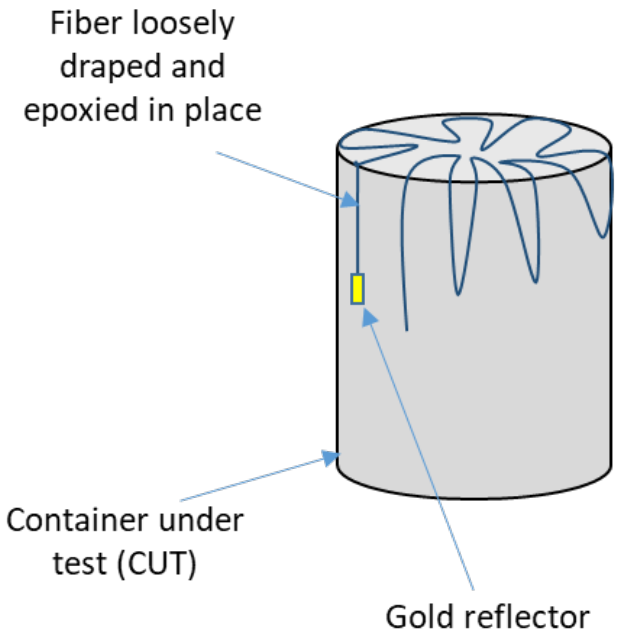
# Problem Background

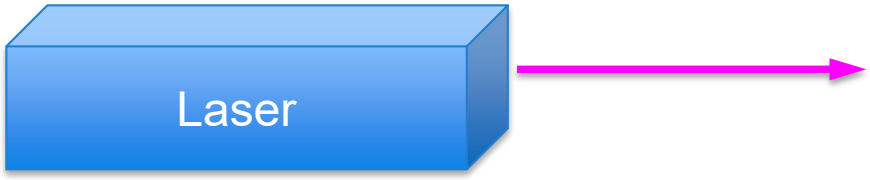
- **Addressing the modernization of IAEA optical fiber seals, which are decades old technology.**
- **Existing optical fiber seals do not have an encoding of the light signals that could render them tamper-proof.**

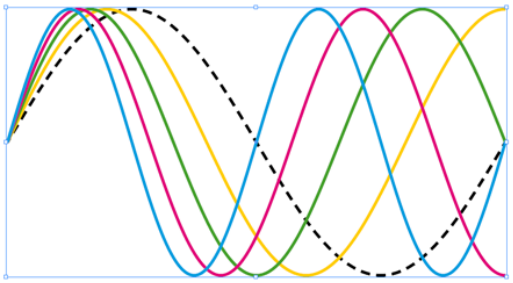


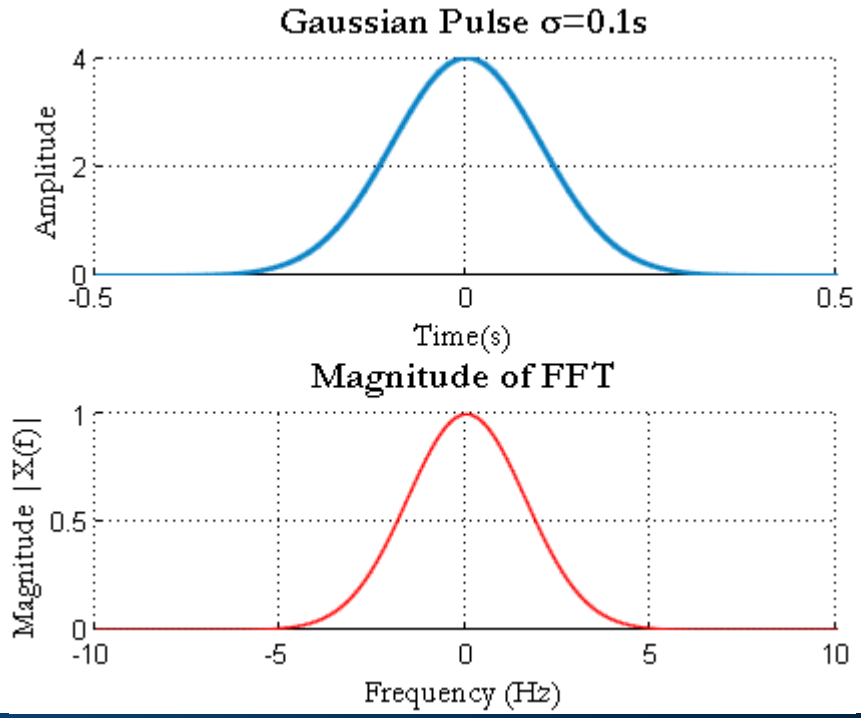

Schematic of fiber optic seal

# Physics Background

- Based on wave mechanics
- A short duration laser pulse can be Fourier Transformed
- Gaussian in time ➔ Gaussian in wavelength
- So, mathematically represented as a set of sine waves of various amplitudes, but infinite duration in time.

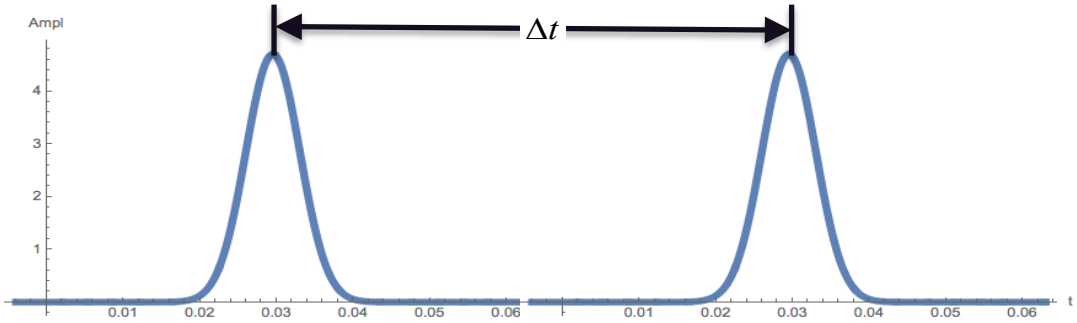




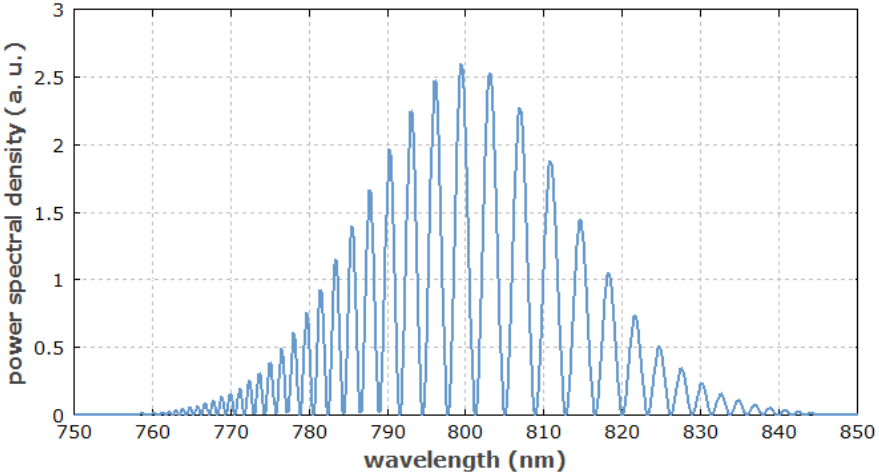
# Now Consider Two Laser Pulses

- **Short duration.**
- **Reasonably close in time, but not overlapping in time.**



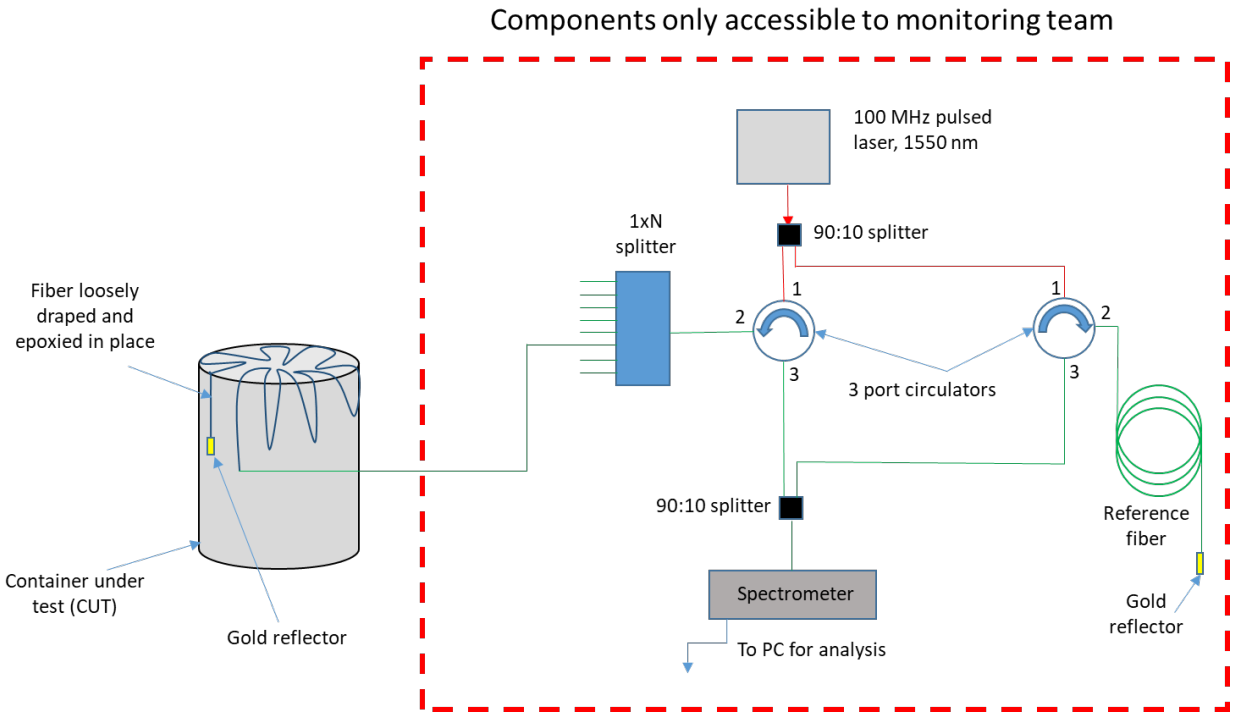

- **The Fourier Transform becomes:**
- **The pulses interfere spectrally in the wavelength domain!**
  - The reason is the Fourier Transform components of the second pulse are phase shifted by:

$$\Delta\phi_\omega = \omega\Delta t$$

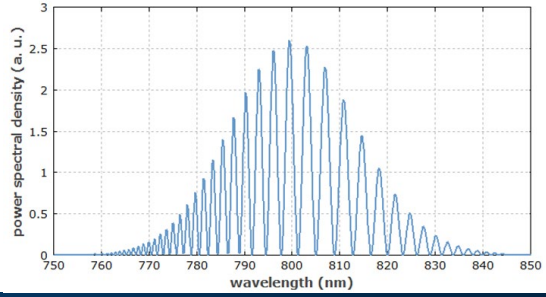


# Now Consider a Basic Fiber Interferometer

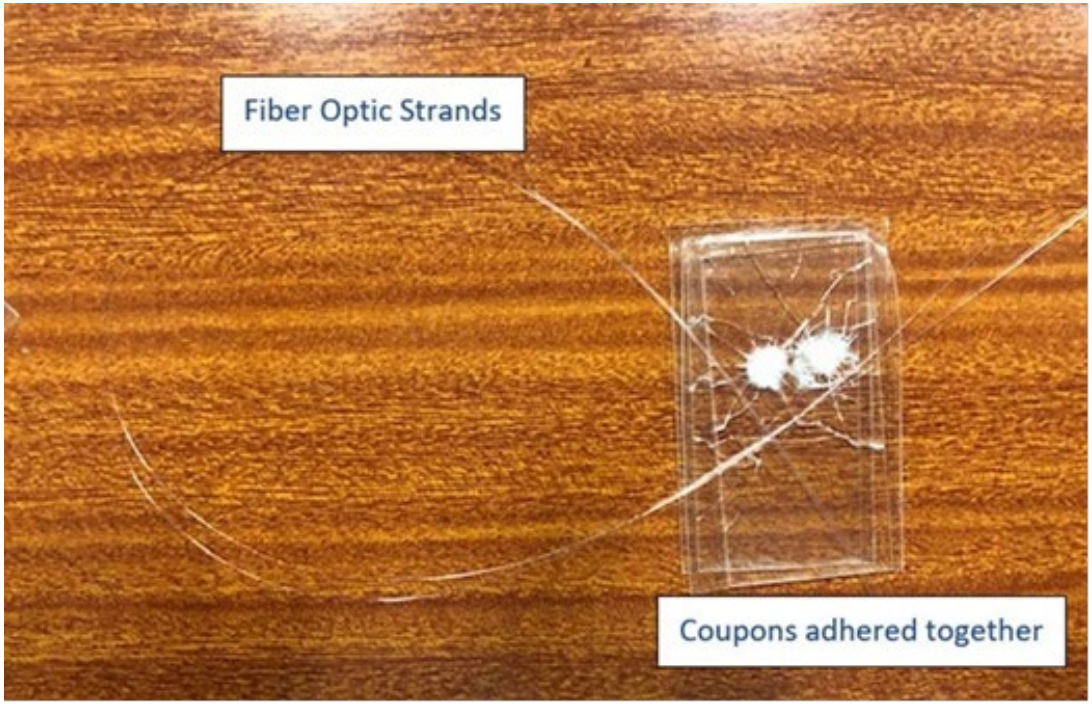
- **Two closely timed pulses from a single laser pulse because beam is split and recombined. Lengths of reference and test legs are close, but not identical**




Qualitatively produces the same spectral interferogram.



# Now Consider Replacing Gold Reflector on Test Fiber With:




- **Damages fiber at multiple locations, which creates multiple reflections at:**
  - Different amplitudes and
  - Slightly different times
- **All spectrally interfere with each other and the reference pulse.**

# The Resulting Spectrum:

- Very complicated spectrum.
- For, say, 10 reflected pulses, there are: $C = \binom{n}{k} = \frac{n!}{k!(n-k)!} = \frac{11!}{2!9!} = 55$

  combinations of one pulse with another
- Each of these produce a unique spectrum, then all then superpose ➔ 55 individual spectra superposed.
- Very difficult to duplicate with a ersatz fiber, especially when the reference leg length, the spectrometer resolution, and the laser pulse width are all unknown.
- Further, the amplitude of the reflections vary depending on the fiber damage.

# Application Summary

- **Laser / optical components are all COTS, (telecommunications technology).**
- **Similar configuration is already at use at DARHT / J-4 for vessel strain measurements as the: Spectral Interferometry for Transient Strain (SITS)**
- **Nominal production cost for this system would be ~$50k**
  - With time multiplexer, could service 50 – 100 separate containers
- **Applications are:**
  - Classical IAEA Seals